When testing just doesn't cut it

Lars Hupel
Lambda Days
2023-06-05

Giesecke+Devrient
Creating Confidence

Where would this line be used?

```
int mid = (low + high) / 2
```

… and what's wrong with it?

```
int mid = (low + high) / 2
```

BLOG ›

Extra, Extra - Read All About It: Nearly All Binary Searches and Mergesorts are Broken

FRIDAY, JUNE 02, 2006

Posted by Joshua Bloch, Software Engineer


HULK SMASH THE STATE

Sorting in Java

```
list so
java.lang.ArrayIndexOutOfBoundsException: 19
        at java.util.ComparableTimSort.pushRun(ComparableTimSort.java:352)
        at java.util.ComparableTimSort.sort(ComparableTimSort.java:181)
        at java.util.ComparableTimSort.sort(ComparableTimSort.java:146)
        at java.util.Arrays.sort(Arrays.java:472)
        at BreakTimSort.run(BreakTimSort.java:68)
        at BreakTimSort.main(BreakTimSort.java:72)
```

OpenJDK's java.utils.Collection.sort() is broken: The good, the bad and the worst case*

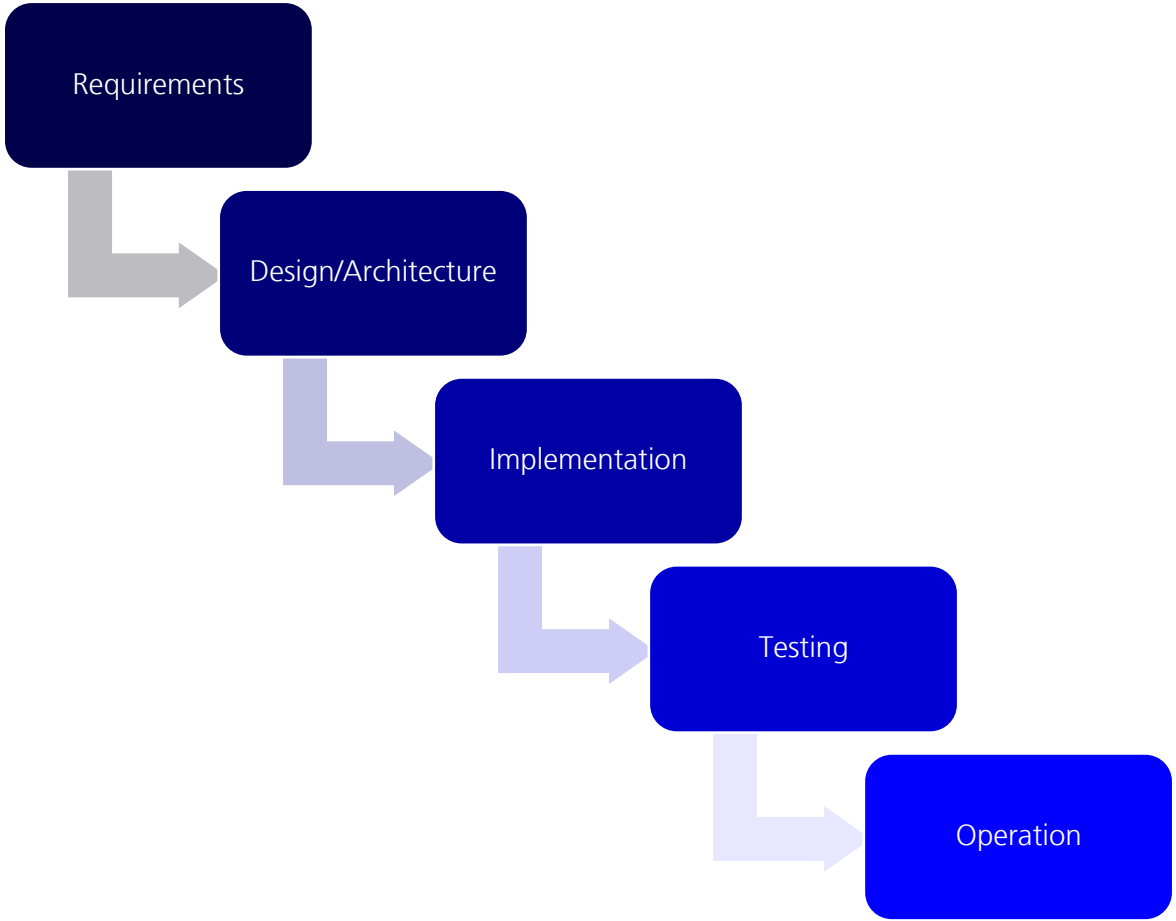
Stijn de Gouw[1,2], Jurriaan Rot[3,1], Frank S. de Boer[1,3], Richard Bubel[4], and Reiner Hähnle[4]

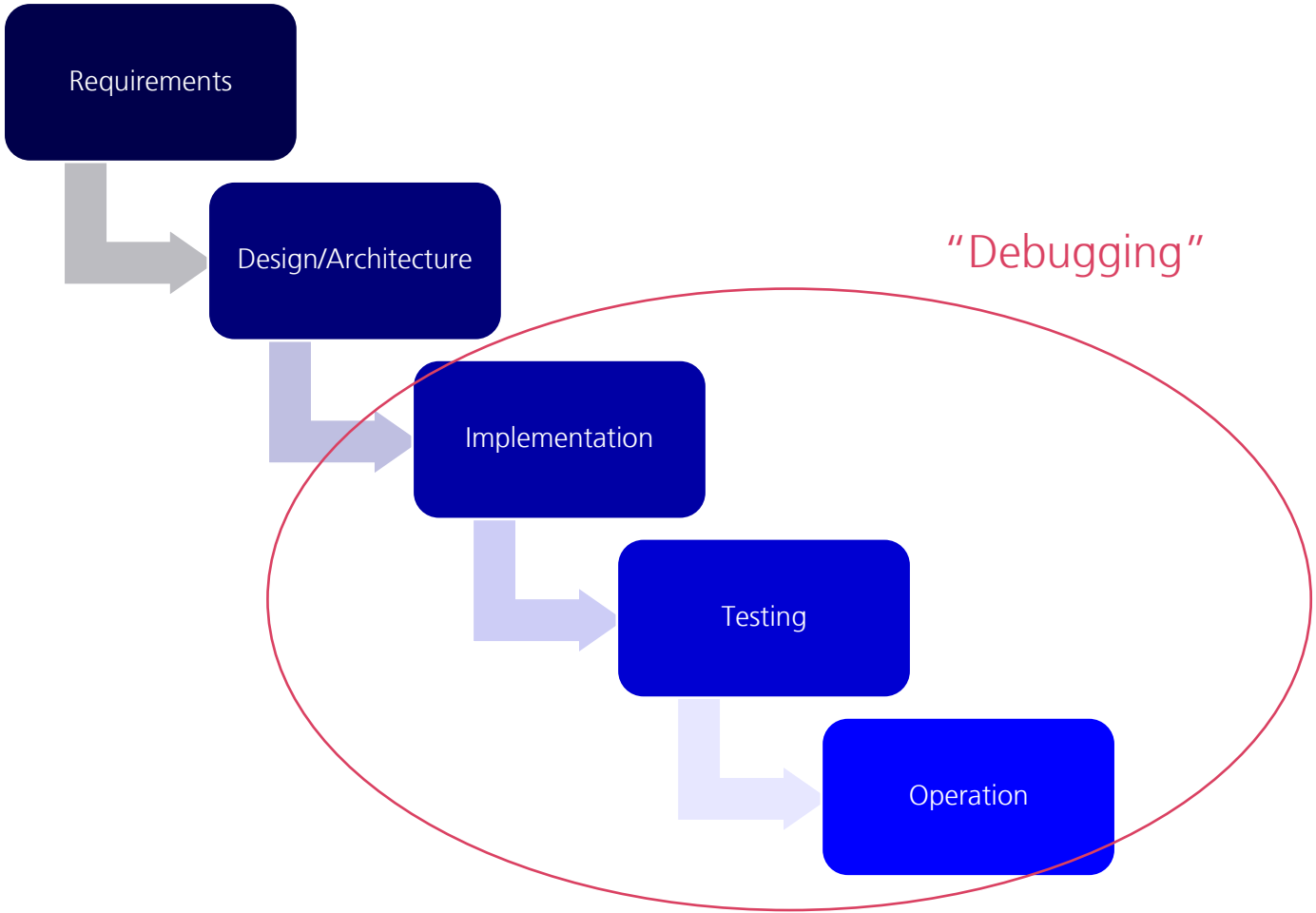
[1] CWI, Amsterdam, The Netherlands
[2] SDL, Amsterdam, The Netherlands
[3] Leiden University, The Netherlands
[4] Technische Universität Darmstadt, Germany

CAV 2015

1700 Started Cosine Tape (Sine check)
1525 Started Mult + Adder Test.
1545  Relay #70 Panel F
(moth) in relay.
First actual case of bug being found.
1700 1630 Arctangent started.
closed down.

Programming & Bugs


Requirements
Design/Architecture
Implementation
Testing
Operation


Requirements
Design/Architecture
Implementation
Testing
Operation
“Debugging”

Simple Testing Can Prevent Most Critical Failures

An Analysis of Production Failures in Distributed Data-intensive Systems

Ding Yuan, Yu Luo, Xin Zhuang, Guilherme Renna Rodrigues, Xu Zhao,
Yongle Zhang, Pranay U. Jain, Michael Stumm
University of Toronto

Abstract

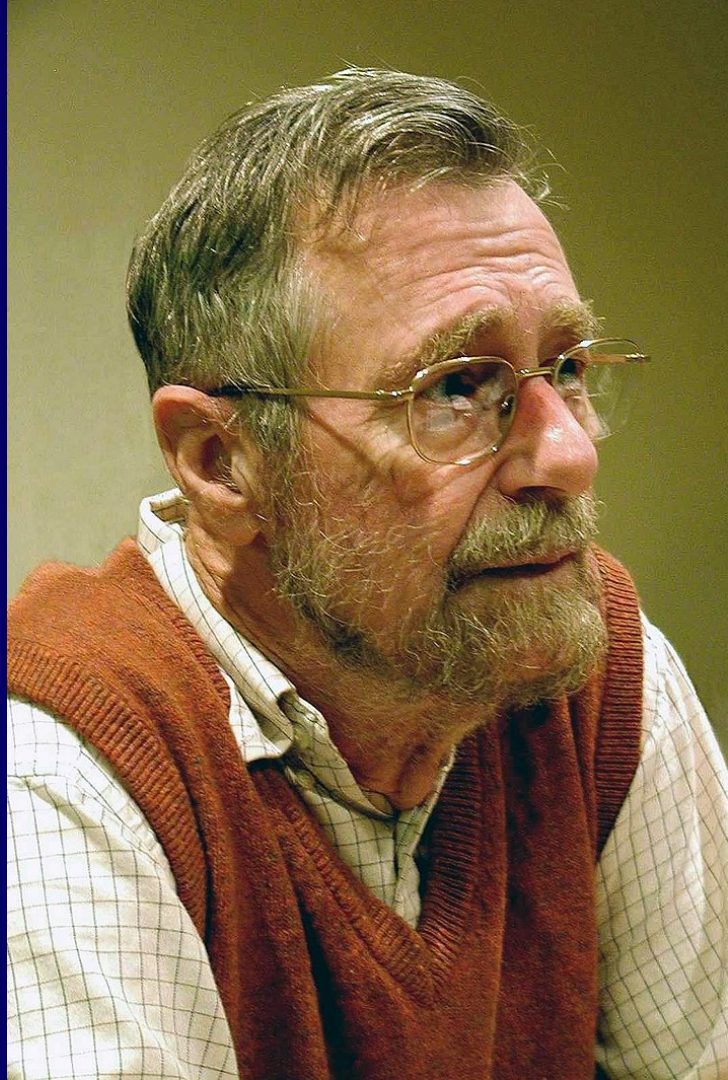
Large, production quality distributed systems still fail periodically, and do so sometimes catastrophically, where most or all users experience an outage or data loss. We present the result of a comprehensive study investigating 198 randomly selected, user-reported failures that occurred on Cassandra, HBase, Hadoop Distributed File System (HDFS), Hadoop MapReduce, and Redis, with the goal of understanding how one or multiple faults eventually evolve into a user-visible failure. We found

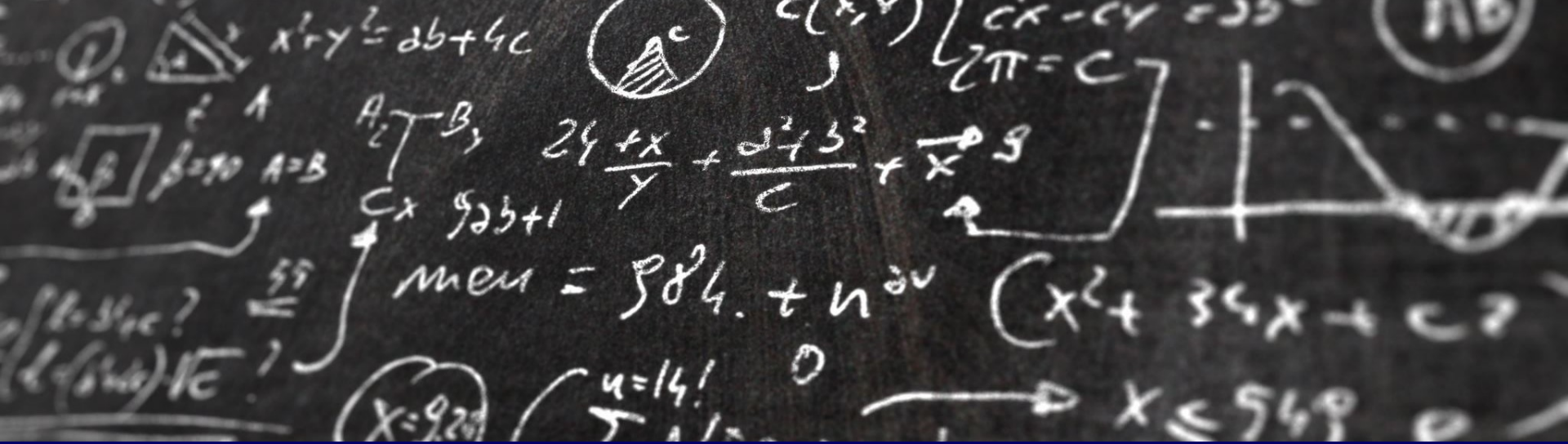
raises the questions of *why these systems still experience failures* and *what can be done to increase their resiliency*. To help answer these questions, we studied 198 randomly sampled, user-reported failures of five data-intensive distributed systems that were designed to tolerate component failures and are widely used in production environments. The specific systems we considered were Cassandra, HBase, Hadoop Distributed File System (HDFS), Hadoop MapReduce, and Redis.

Our goal is to better understand the specific failure manifestation sequences that occurred in these systems

OSDI 2014

“Program testing can be a very effective way to show the presence of bugs, but it is hopelessly inadequate for showing their absence”



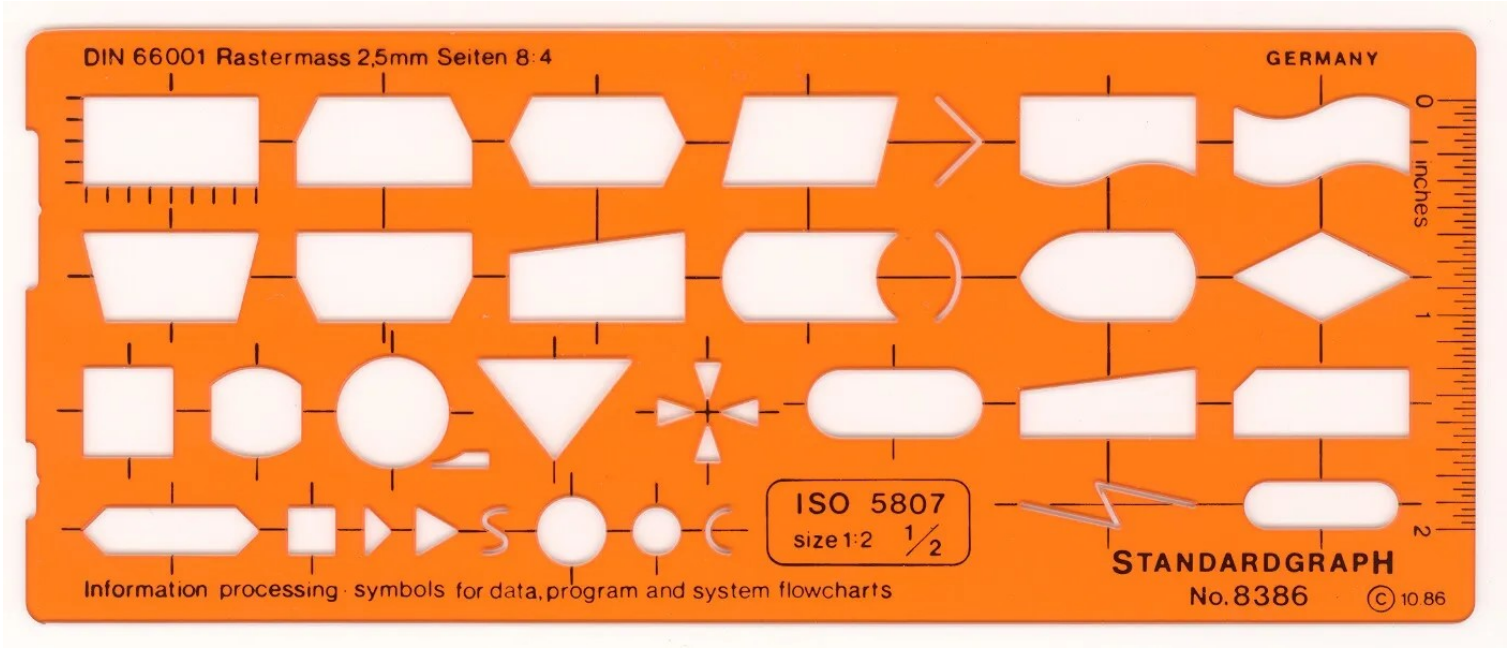


Formal Methods

"Formal Methods refers to mathematically rigorous techniques and tools for the specification, design and verification of software and hardware systems"


You have already used Formal Methods!
... without knowing it

ISO 5807 Flowchart



ISO 5807:1985

9.2.1 Basic process symbol

Process

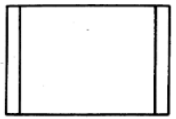
This symbol represents any kind of processing function, for example, executing a defined operation or group of operations resulting in a change in value, form or location of information, or in the determination of which one of several flow directions is to be followed.

Syntax

9.2.2.1 Predefined process

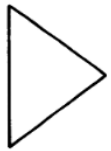
This symbol represents a named process consisting of one or more operations or program steps that are specified elsewhere, for example, a subroutine, a module.

Semantics



9.3.2.1 Control transfer

This symbol represents immediate transfer of control from one process to another, sometimes with a chance of the direct return to the activating process after the activated process completes its actions. The type of control transfer should be named inside the symbol, for example, call, fetch, event.

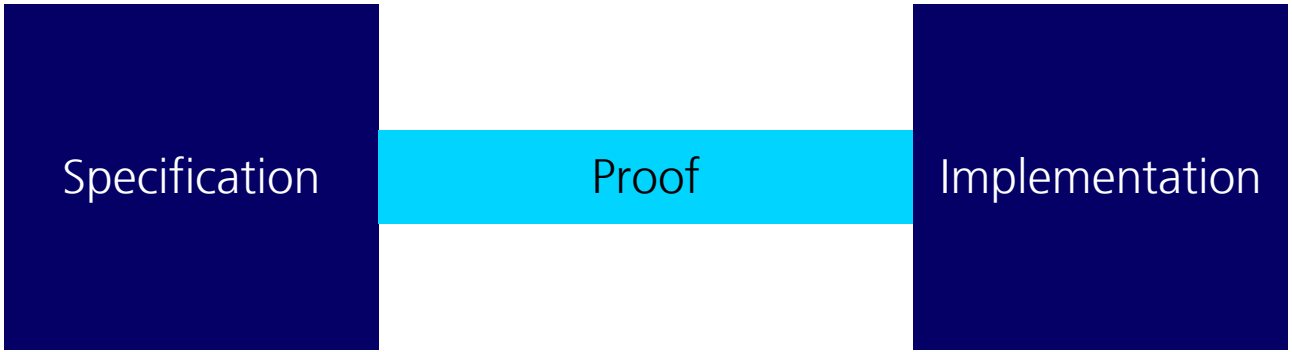


```ts
interface Obj {
  a: number
  b: string
}

const obj: Obj = {
  a: 1,
  b: 'hi'
}

function fn(key: keyof Obj, value: Obj[keyof Obj]) {
  let foo = obj[key]
  obj[key] = value
}

fn("a", 2)
```

input.ts 1 of 1 problem

```
Type 'string | number' is not assignable to type 'never'.
  Type 'string' is not assignable to type 'never'. (2322)
```

What is verification?



Binary search, again!

```
int mid = (low + high) / 2;
```

Binary search, again!

Implementation

```
assert low <= high;
assert 0 <= low;
int mid = (low + high) / 2;
assert low <= mid;
assert mid <= high;
```

Specification

Binary search, again!

$$\forall low, high \in Int_{32}.$$
$$low \leq high \Rightarrow$$
$$0 \leq low \Rightarrow$$
$$low \leq \left\lfloor \frac{(low +_{32} high)}{2} \right\rfloor$$

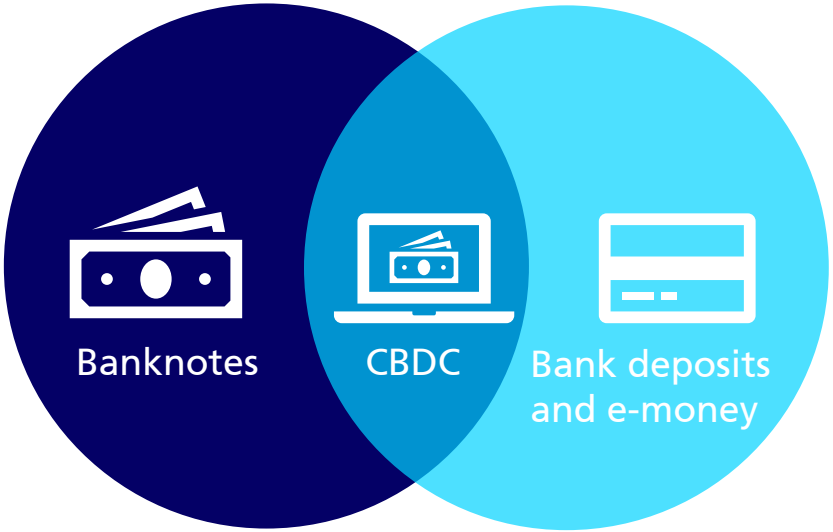
Formal Methods in practice


GOLD
GOLD


100
EURO

Central Bank Digital Currency

Issued by the central bank



Digital money

Our customers

- central banks
- commercial/retail banks
- payment service providers

EUROPE

U.K. bank mistakenly issues duplicate payments to customers' accounts

January 3, 2022 · 7:05 AM ET

Heard on Morning Edition

Zelle Issue: Bank of America Users Report Negative Balances After Bug

Zelle users took to Twitter to bemoan the loss of funds from their accounts as well as a lack of response from Bank of America and Zelle about the issue.

TONY OWUSU • JAN 18, 2023 11:38 AM EST

Chase has resolved technical issue that caused thousands of reports of incorrect account balances

By Clare Duffy, CNN Business

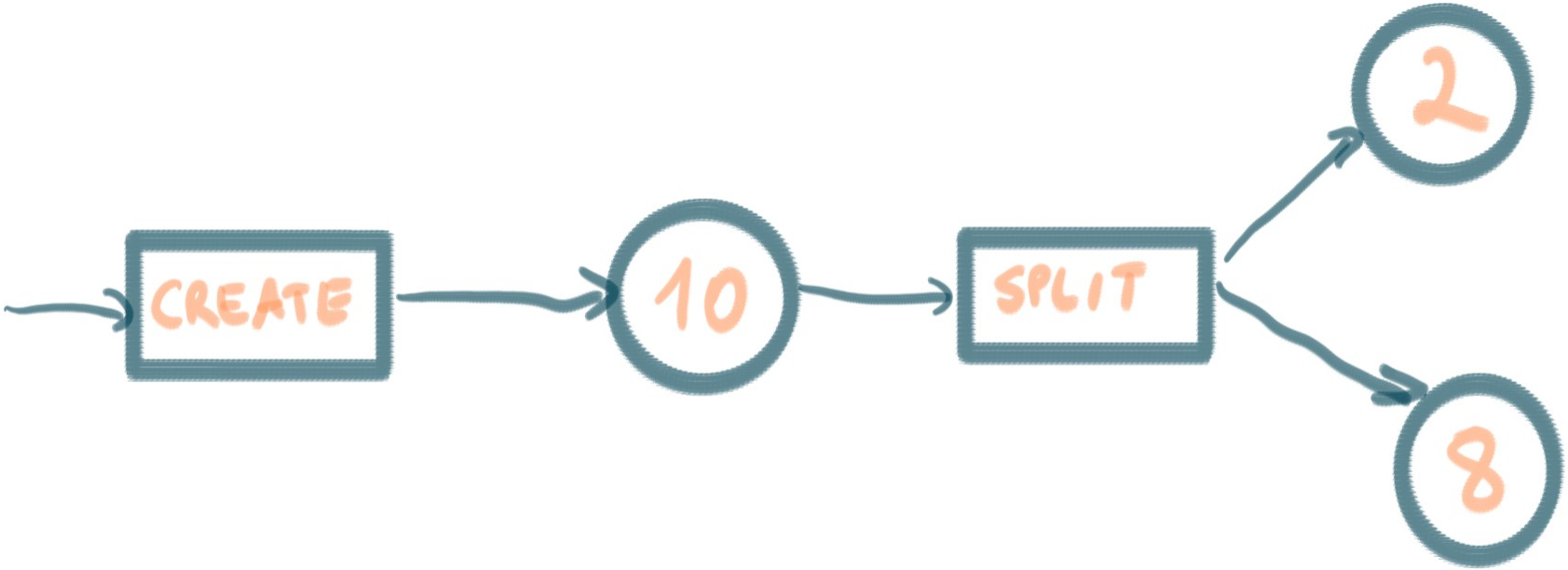
Updated 2:58 PM EDT, Sun June 28, 2020

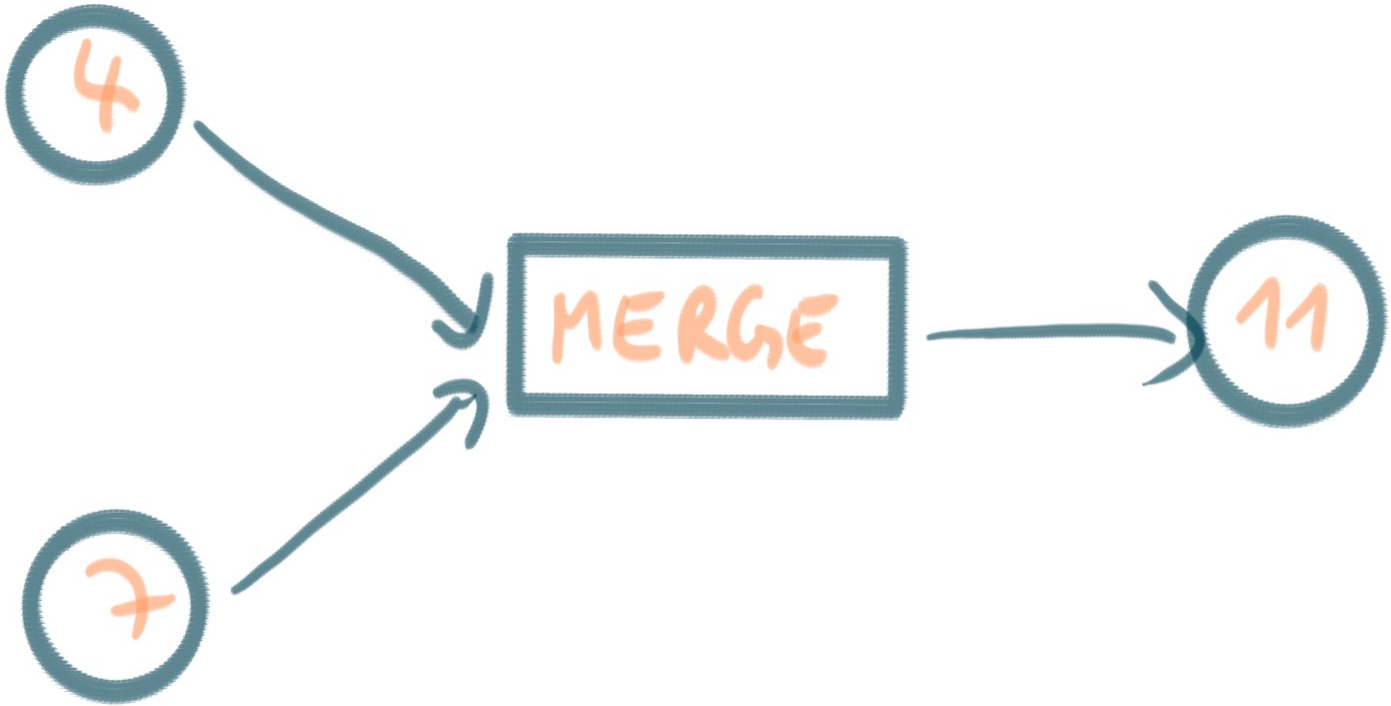
'My savings are missing': technical glitch reduces Barclays customers' cash to zero

By Dominic Webb

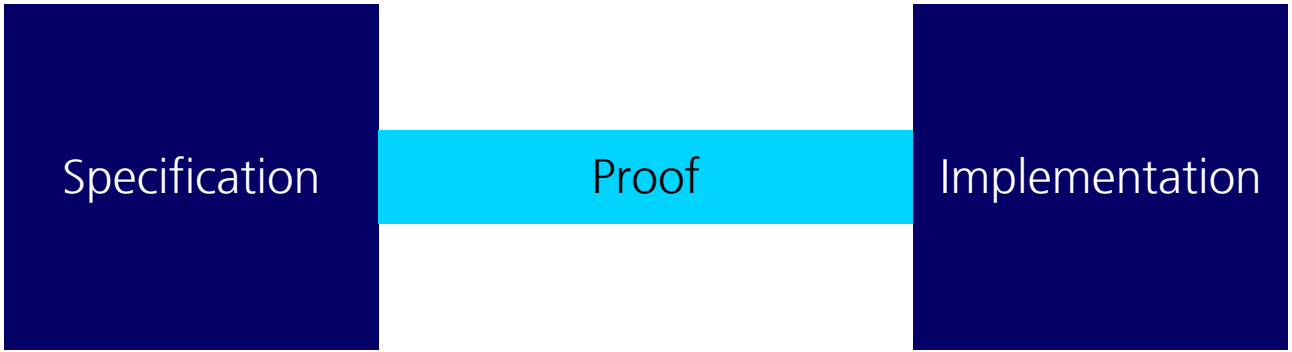
21 February 2019 • 7:06pm

How money is represented in G+D Filia®


CREATE
10
SPLIT
2
8

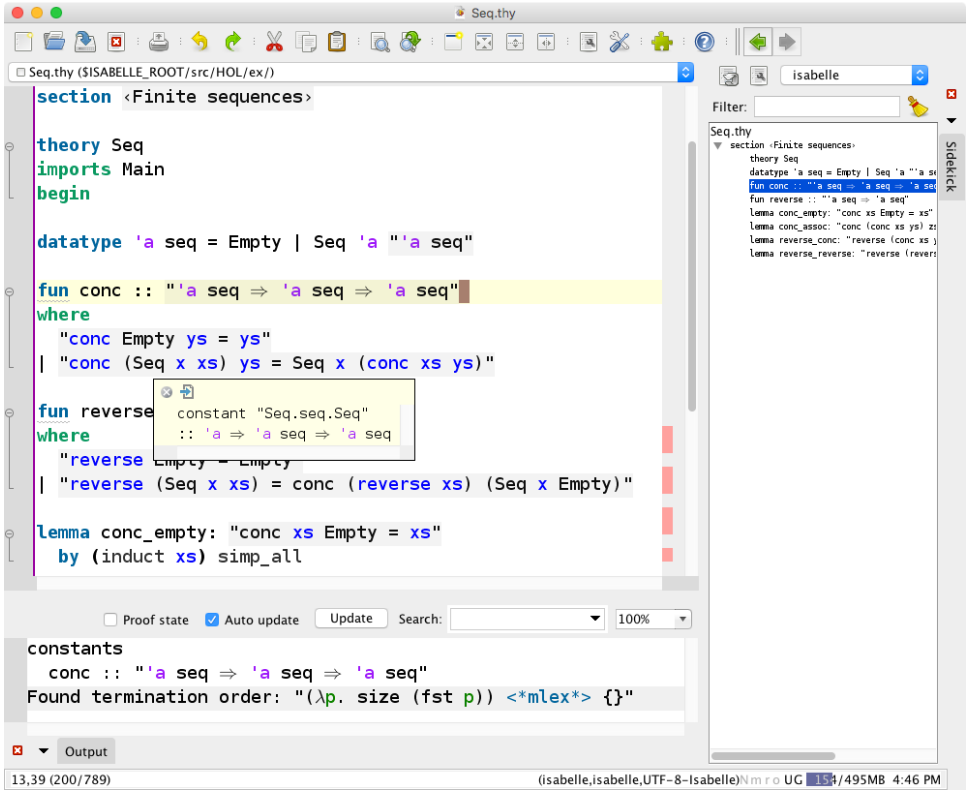

4
7
MERGE
11

From specification to implementation

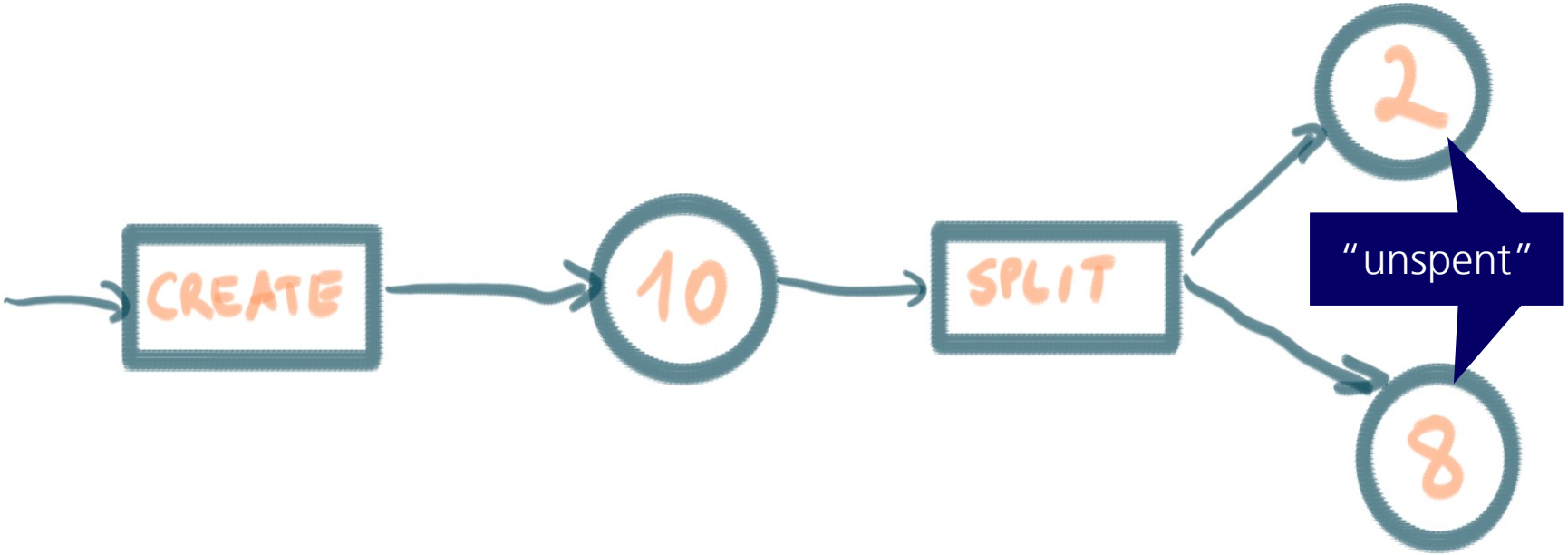


From specification to implementation

Isabelle to the rescue!

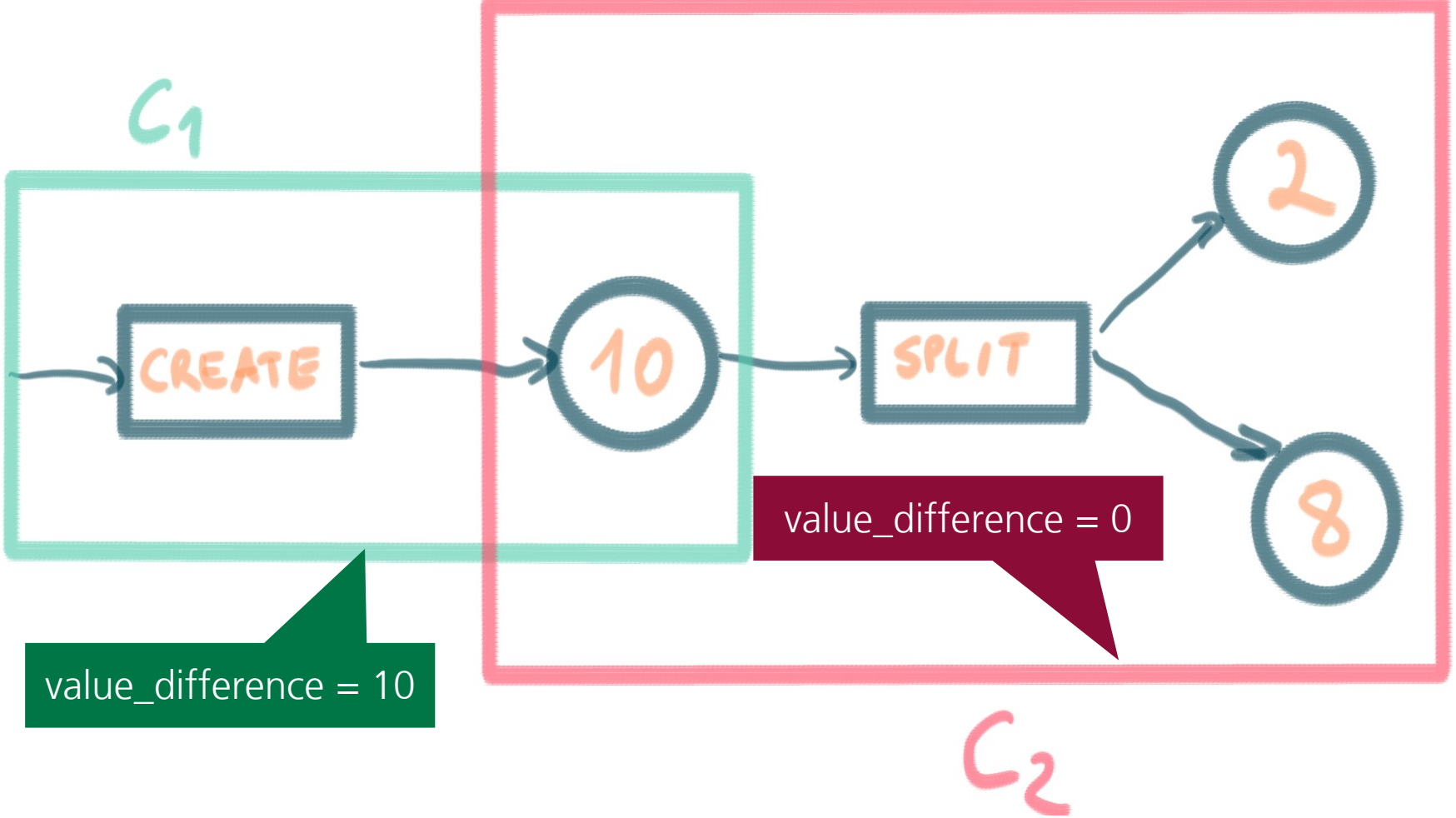


“Isabelle/HOL =
Functional Programming
+ Logic”


CREATE
10
SPLIT
2
8
"unspent"

Example: Money in circulation

```
definition graph_balance :: nat where
‹graph_balance = (ΣN ∈ unspent. value N)›
```

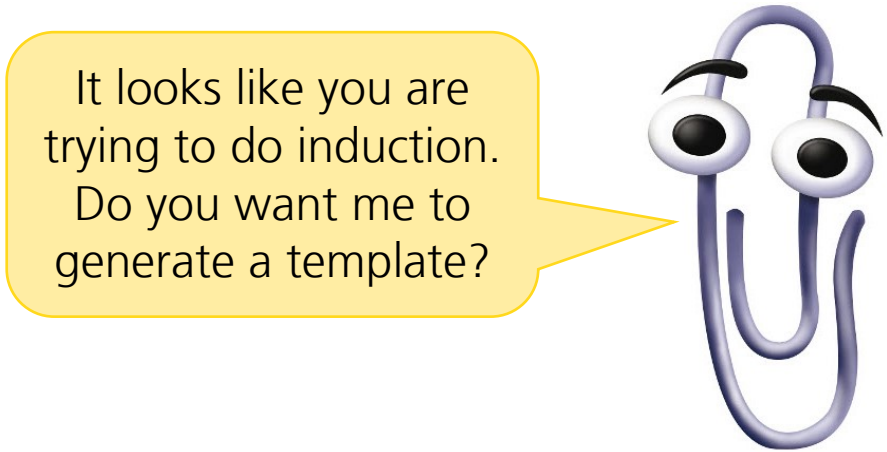

C1
CREATE
10
SPLIT
2
8
value_difference = 0
value_difference = 10
C2

Example: Money in circulation

```
lemma graph_balance_eq_value_difference:
  ‹graph_balance = ¦(Σc ∈ graph. value_difference c)¦›
```

Example: Money in circulation

```
lemma graph_balance_eq_value_difference_pos:
  shows ‹0 ≤ (Σc ∈ graph. value_difference c)›
  shows ‹graph_balance = ¦(Σc ∈ graph. value_difference c)¦›
proof (induction)
  (* ... *)
qed
```



Example: Money in circulation

```
lemma graph_balance_eq_value_difference_pos:
  shows ‹0 ≤ (Σc ∈ graph. value_difference c)›
  shows ‹graph_balance = ¦(Σc ∈ graph. value_difference c)¦›
proof (induction)
  case empty
  (* ... *)
next
  (* ... *)
qed
```

base case

steps

It’s not just us

Google Announces KataOS As Security-Focused OS, Leveraging Rust & seL4 Microkernel

Written by Michael Larabel in Google on 16 October 2022 at 06:10 AM EDT. 45 Comments

Google this week has announced the release of KataOS as their newest operating system effort focused on embedded devices running ambient machine learning workloads. KataOS is security-minded, exclusively uses the Rust programming language, and is built atop the seL4 microkernel as its foundation.

CLOUD AND SYSTEMS

How to integrate formal proofs into software development

ICSE paper presents techniques piloted by Amazon Web Services' Automated Reasoning team.

By Daniel Schwartz-Narbonne

May 27, 2020

Verification

In addition to our desire to determine how Parallel Commits fits into the broader landscape of distributed systems theory, we also wanted to formally specify the protocol and prove its safety properties through verification. To do so, we turned to TLA+, a formal specification language developed by Leslie Lamport. TLA+ has been used to great success to verify systems and algorithms ranging from DynamoDB and S3 all the way to the Raft Consensus Algorithm used by CockroachDB.

Formal Methods at Intel — An Overview

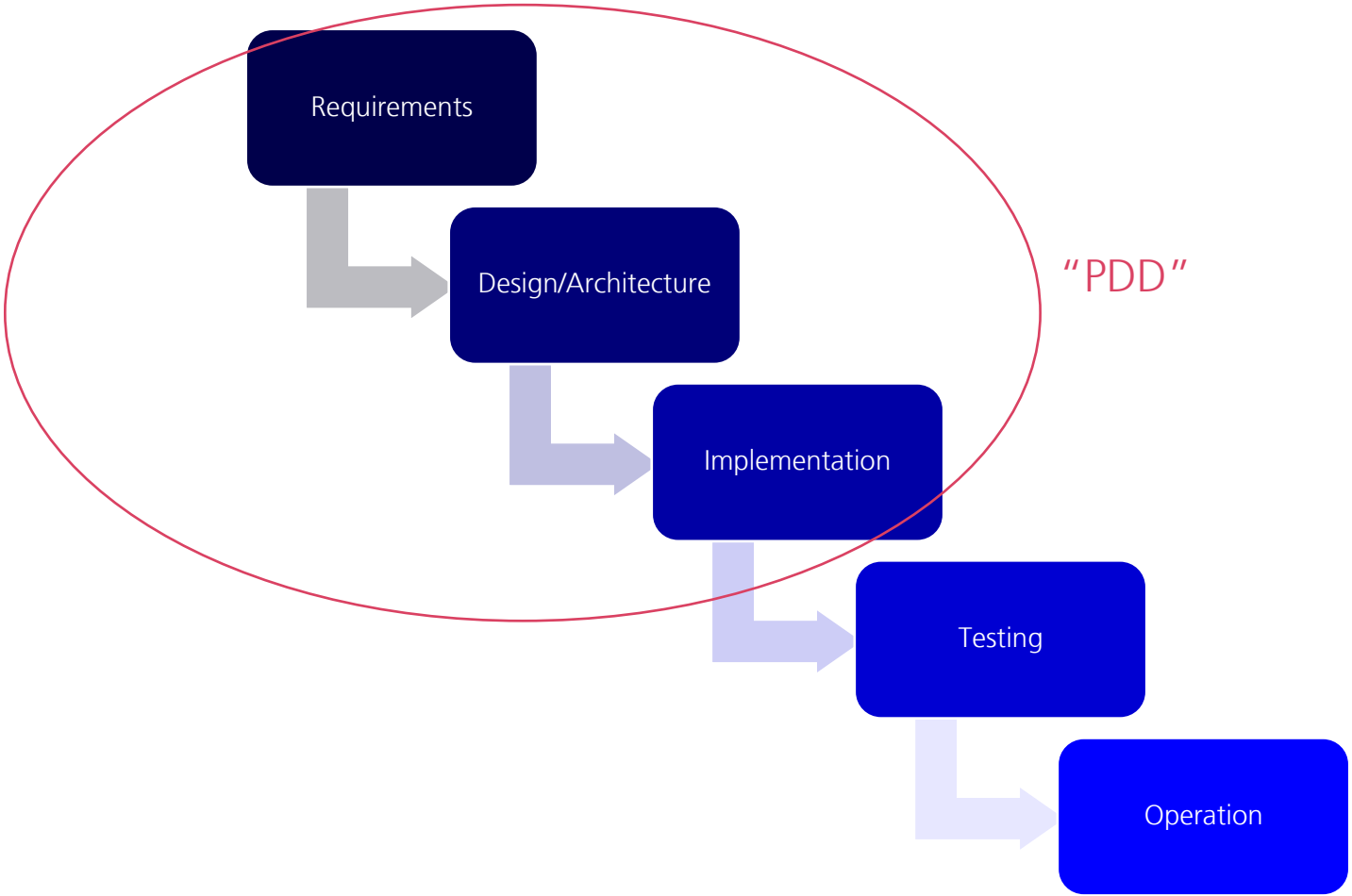
John Harrison
Intel Corporation

11th Annual Oregon Programming Languages Summer School
University of Oregon, Eugene
26th July 2012 (19:00–20:00)

Proof-Driven Development (PDD)


PACCAR
MEIL
ELP 1215
ELP-1215
SP-SÃO CARLOS


Hold Near Reader
.... 2009
AIRFRANCE
AMERICAN EXPRESS


Requirements
Design/Architecture
Implementation
Testing
Operation
“PDD”


MORROW
MORROW

Questions?
Answers!

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https://lars.hupel.info

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Image sources

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- César A. Muñoz: https://shemesh.larc.nasa.gov/people/cam/
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